# Safeguards & Security for Advanced Reactors

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October 16, 2015

Presented at: ORNL Workshop on Molten Salt Reactor Technologies

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U.S. Department of Energy

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# Disclaimer

This is not an evaluation of the MSR or of any other nuclear energy system.

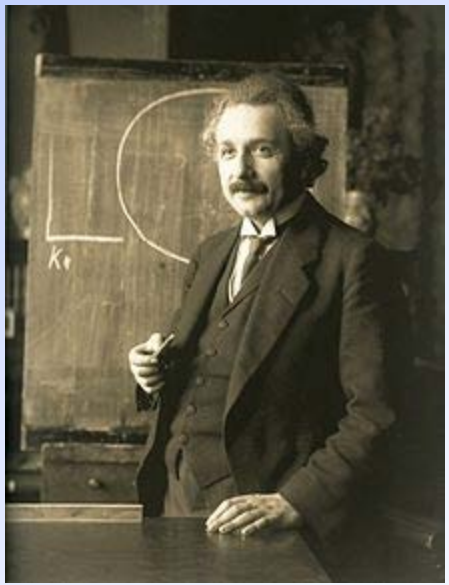
As requested by the workshop organizer it is highlight summary of safeguards and security issues for new reactors in general

# Beginning of Nuclear Fission Age

Discovered by Lise Meitner and colleagues in Germany in 1938.

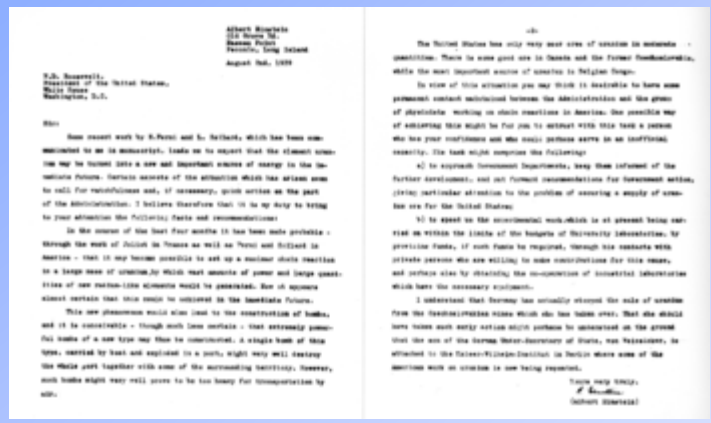
Bombardment of heavy nuclei led to smaller fission fragments plus excess energy

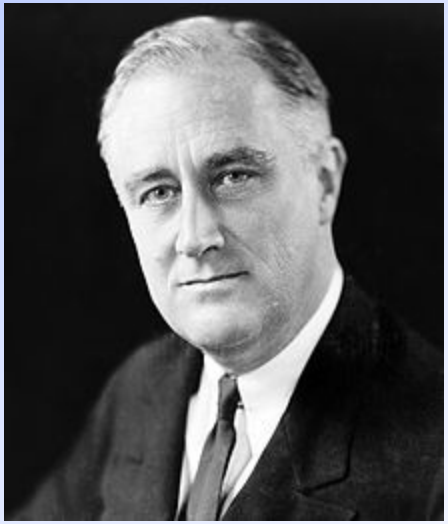
$E = mc^2$



# Call to War

## Einstein letter* to President Roosevelt: 1939





Alerts Roosevelt to potential power of nuclear fission chain reaction and that Germany may be pursuing weapons development. Suggests US government alignment with *"group of physicists"*

→ Birth of Manhattan Project

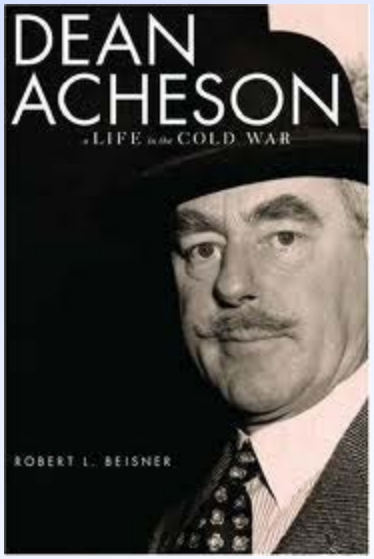
**letter written in Peconic, NY*

# Aftermath of War: 1946-53

Acheson-Lilienthal Report: 1946

*Discussed possible methods for the international control of nuclear weapons and the avoidance of future nuclear war*

→ Cold War

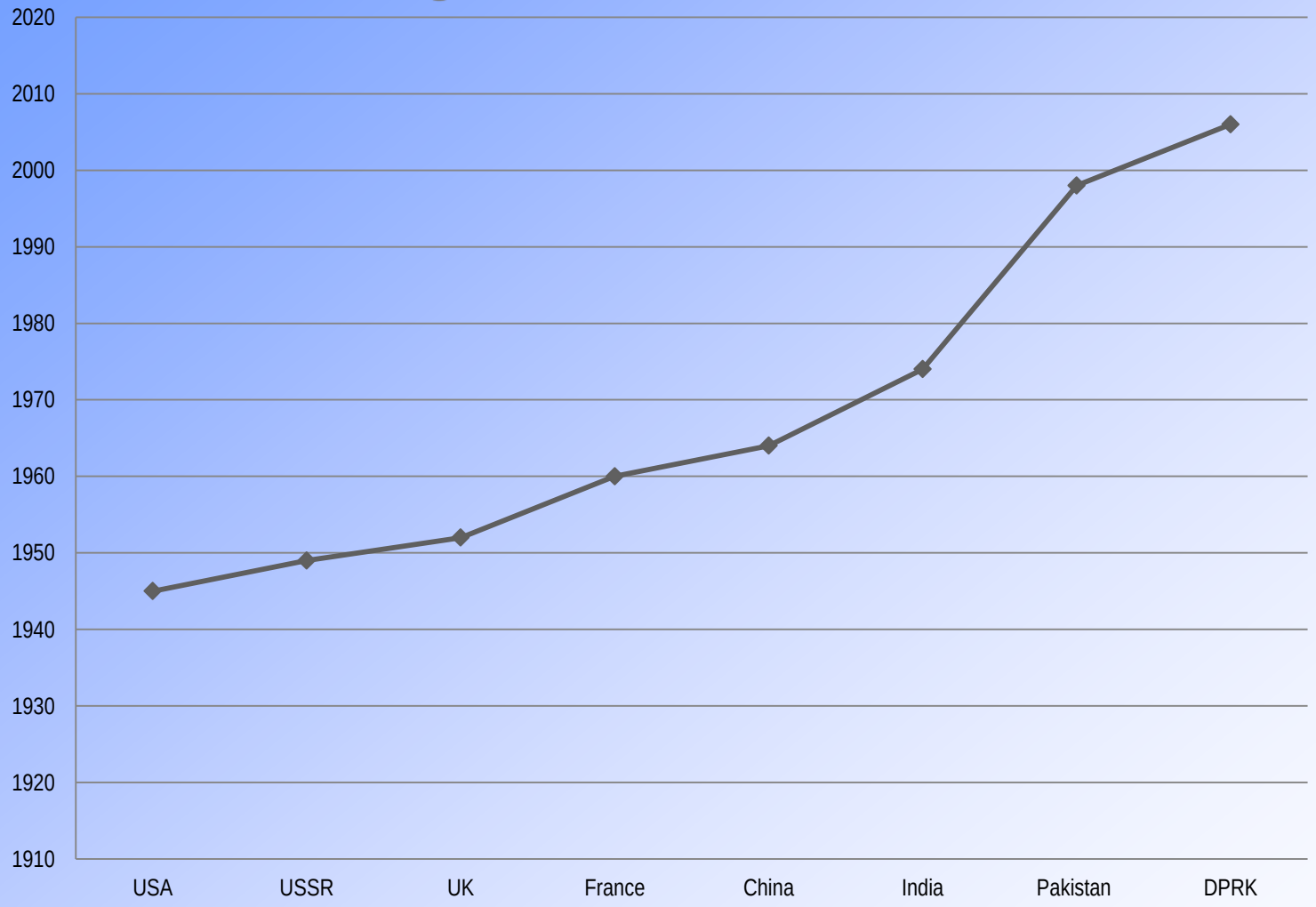



Eisenhower: Atoms for Peace: 1953

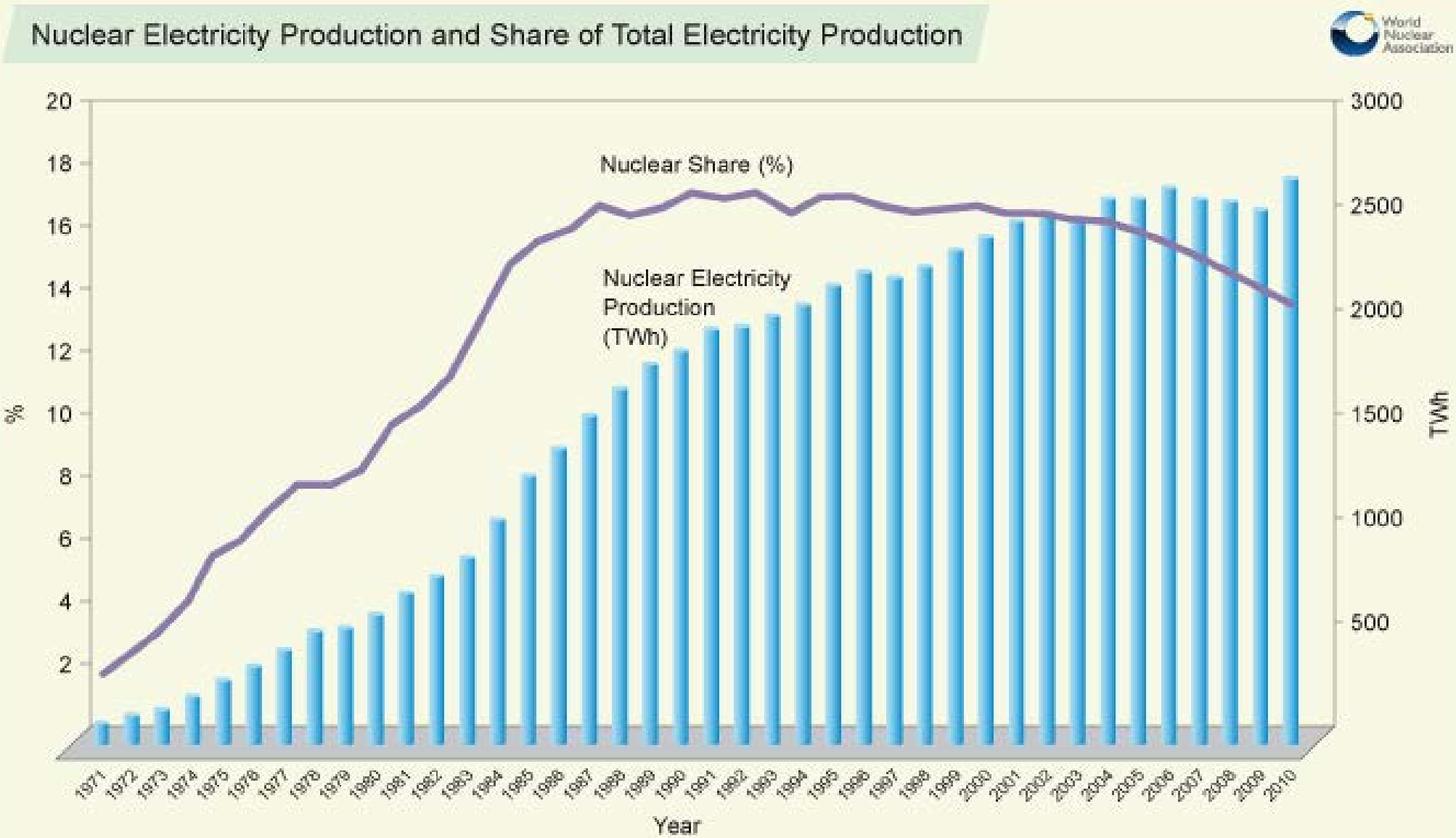
*Nuclear science and technology to benefit mankind*

→ Nuclear power plants

# Country vs. Year of First Test




*"I am haunted by the feeling that by 1970, unless we are successful, there may be 10 nuclear powers instead of 4, and by 1975, 15 or 20."* –John Kennedy, 1963


Nuclear Electricity Production and Share of Total Electricity Production
World Nuclear Association
Nuclear Share (%)
Nuclear Electricity Production (TWh)
%
TWh
Year
20
18
16
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12
10
8
6
4
2
3000
2500
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# Challenges for Nuclear Power

- Three Mile Island – 1979
  - o Improved operations
  - o Severe accident risk

- Chernobyl – 1986
  - o Improved safety of Soviet-designed reactors
  - o End of Cold War

- Fukushima - 2011
  - o Lesson learned worldwide – ongoing efforts

# Challenges for Nuclear Power

- More Generally
  - Waste Management - NIMBY
  - Costs – natural gas…fracking
  - Terrorism –post 9/11
  - Weapons

# IAEA Safeguards

Comprehensive Safeguards Agreement (CSA)
"Traditional Safeguards"
*INFCIRC/153 Para. 28: The Safeguards Technical Objective*

... the objective of safeguards is the *timely detection* of *diversion* of *significant quantities* of *nuclear material* from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and *deterrence of such diversion* by the *risk of early detection*...

NOTE:
Current safeguards efforts relate to water-cooled technologies

# Safeguards for Future Reactors ...some considerations

- Accountancy tools and measures may need to be modified for non-conventional fuel types.
- New fuel loading schemes may present novel accountancy challenges.
- Accessibility to the nuclear material, consider:
  - is facility operated continuously,
  - how facility is refueled,
  - location and mobility of facility,
  - existence and locations of other nuclear facilities

# Safeguards for Future Reactors (cont'd)

- Will there be a different approach to physical protection and how might that affect the safeguards tools?
- Will the site or nearby sites have more or less ancillary equipment like hot cells, pin replacement capability, fuel storage, or nuclear research activities?
- Will the containment features be shared by multiple units; will there be underground containment?

# Safeguards for Future Reactors (cont'd)

- Fuel leasing or supply arrangements that avoid on-site storage of fresh and/or used fuel.
- The isolation of the site or mobility of the reactor (sea or rail). Access issues for both inspectorate and the adversary.
- Remote monitoring: Operator / State / IAEA communication

# Safeguards by Design (SBD)

- SBD: process of incorporating features to support international safeguards into nuclear facility designs starting in its conceptual design phase.

- Element of the design process for a new nuclear facility from initial planning through design, construction, operation, and decommissioning.

- SBD includes use of design measures that make the implementation of safeguards at such facilities more effective and efficient

➢ *US Initiative in NNSA/NGSI Program; IAEA Safeguards Department*

# Why early in the Design?

## …some Viewpoints

- Analysts and other non-designers (not all):

*"less costly to introduce safeguards at the beginning of the design process'*

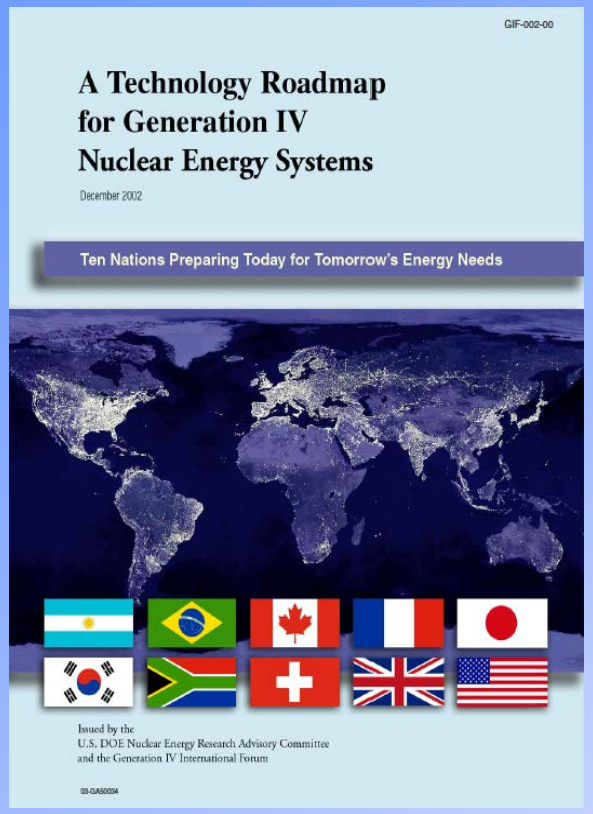
- Facility designers and owners (not all):

*" what do I gain from introducing safeguards early…just meet requirements whenever asked to"*

# Security

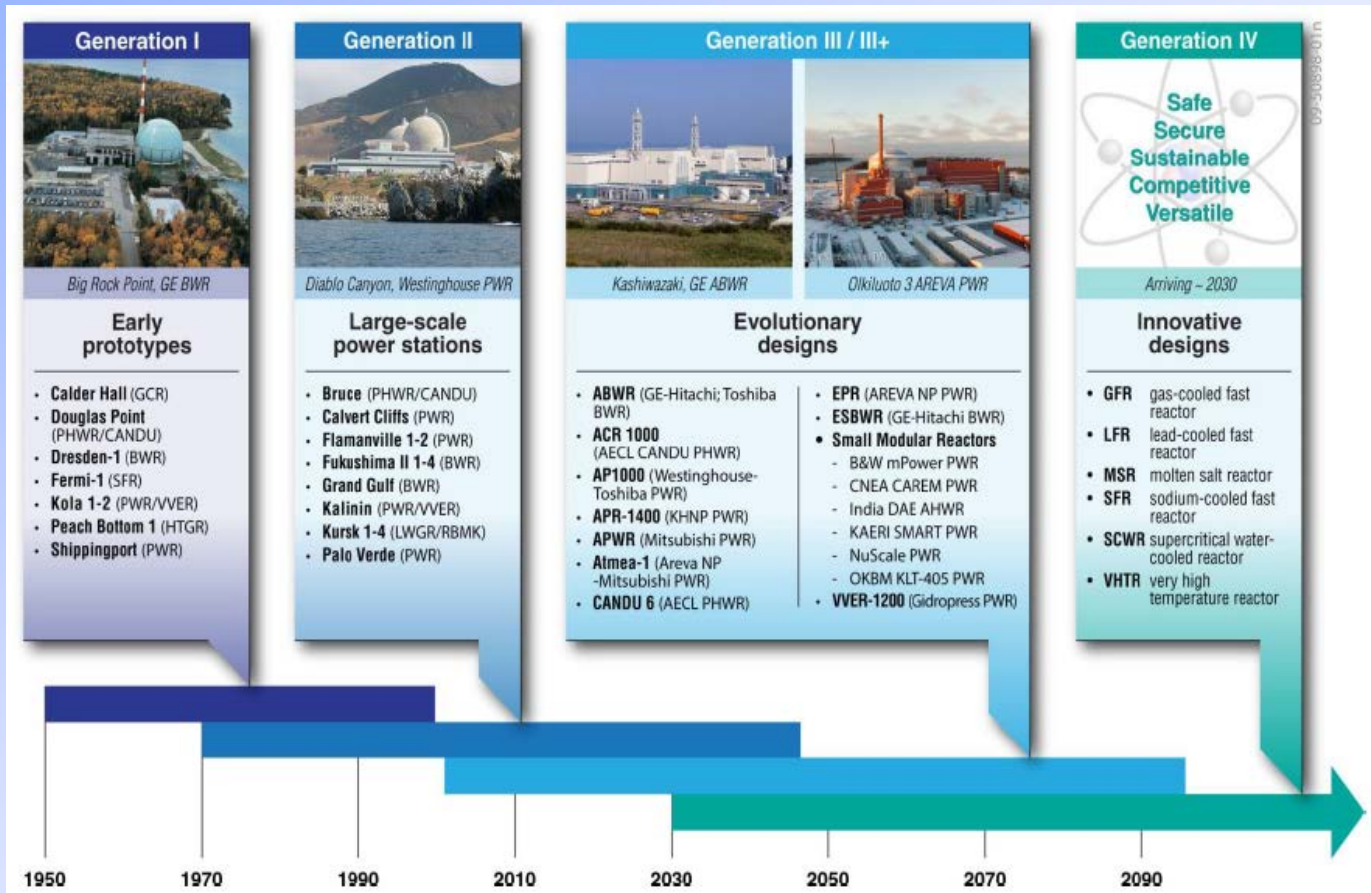
- Country-specific programs – need to work with sensitive information
- USNRC:
  - see, e.g. 10 CFR 73 & 74, 10 CFR 50.54(hh)(2), post-Fukushima
- US Industry – response to 9/11; B.5.b measures, NEI-06-12
- Recent initiatives to risk-inform security-workshops, regulatory considerations

# Generation IV International Forum




Technology Roadmap, 2002

## Generation IV Technology Timeline



# Objectives of Gen-IV Systems Development

## Proliferation Resistance & Physical Protection

assure least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism

## Safety and Reliability

safe and reliable operation

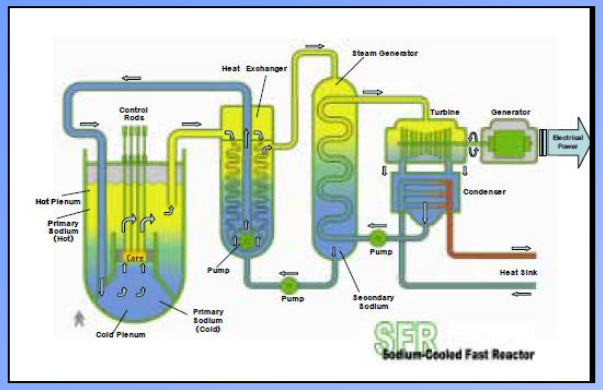
## Sustainability

effective fuel utilization, minimization of nuclear waste

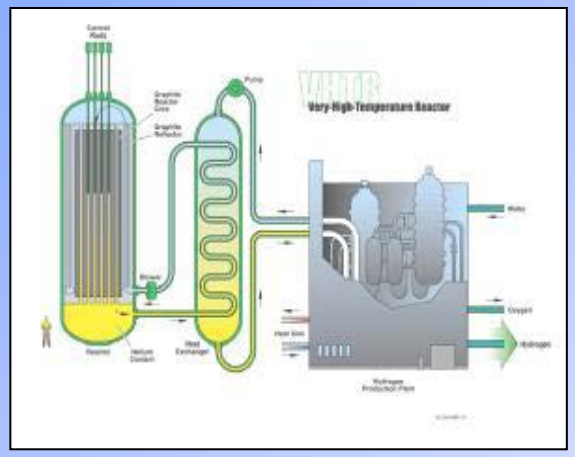
## Economic Competitiveness

life-cycle cost advantage over other energy resources

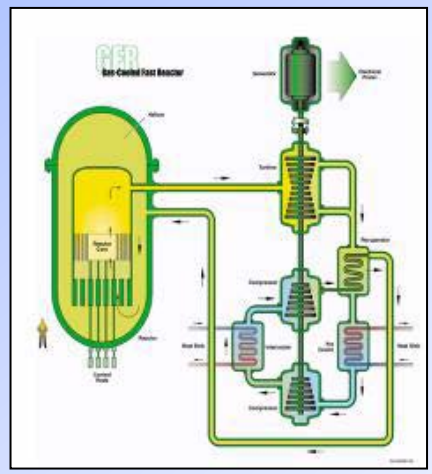
# Six Gen-IV Systems



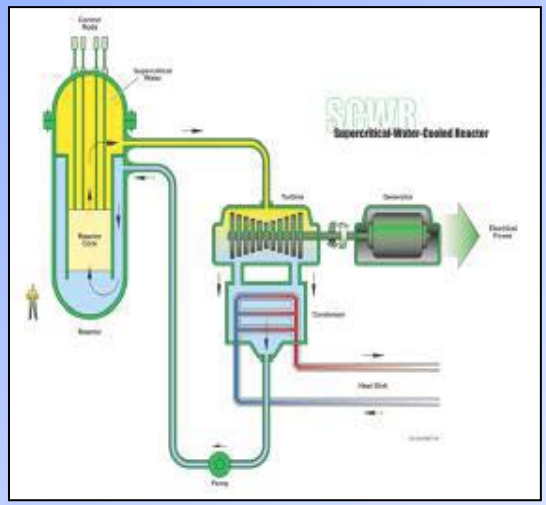

*Sodium-cooled Fast Reactor (SFR)*



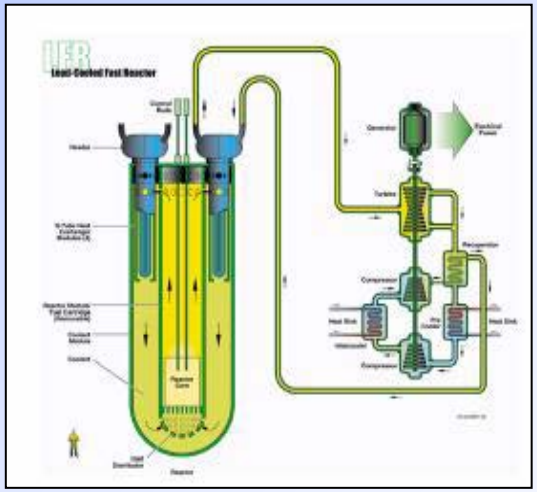

*Very High Temperature Reactor (VHTR)*



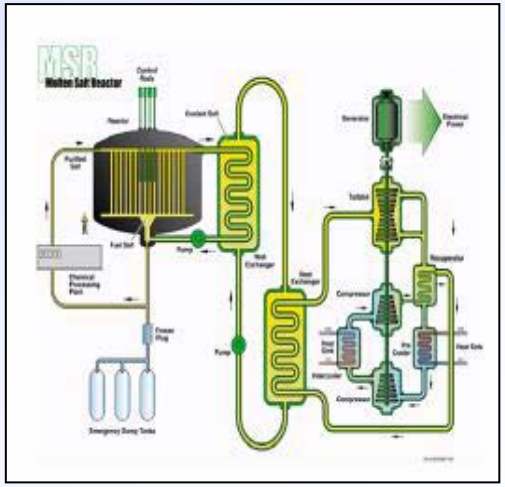

*Gas-cooled Fast Reactor (GFR)*




*Supercritical Water-cooled Reactor (SCWR)*




*Lead-cooled Fast Reactor (LFR)*




*Molten Salt Reactor (MSR)*

# The Gen IV Proliferation Resistance and Physical Protection (PR&PP) Methodology

see: https://www.gen-4.org/gif/jcms/c_40413/evaluation-methodology-for-proliferation-resistance-and-physical-protection-of-generation-iv-nuclear-energy-systems-rev-6

**CHALLENGES** → **SYSTEM RESPONSE** → **OUTCOMES**

## *Threats*

**PR**

- Diversion
- Misuse
- Breakout
- Clandestine Facility

**PP**

- Theft
- Sabotage

## *PR & PP*

**Intrinsic**

Physical & technical design features

**Extrinsic**

Institutional arrangements

e.g. IAEA Safeguards, Guns/Guards/Gates

## *Assessment*

**Measures**

**PR**

- Material Type
- Detection Probability
- Technical Difficulty
- Proliferation Time
- Proliferation Cost
- Safeguards Cost

**PP**

- Adversary Success Probability
- Consequence
- Security Cost

# PR &PP Comparison/Distinctions

<u>Proliferation Resistance</u>

- Host state is adversary
- Threats are
  - Diversion
  - Misuse
  - Breakout
- International Safeguards
- Slow moving events
  (not always)

<u>Physical Protection</u>

- Sub-national is adversary
- Threats are
  - Theft
  - Sabotage
- Domestic Safeguards
- Fast moving events
  (sometimes)

# PR&PP Threat Considerations

| | Proliferation Resistance | Physical Protection |
|---|---|---|
| **Actor Type** | • Host State | • Outsider<br>• Outsider with insider<br>• Insider alone<br>• Above and non-Host State |
| **Actor Capabilities** | • Technical skills<br>• Resources (money and workforce)<br>• Uranium and Thorium resources<br>• Industrial capabilities<br>• Nuclear capabilities | • Knowledge<br>• Skills<br>• Weapons and tools<br>• Number of actors<br>• Dedication |
| **Objectives** (relevant to the nuclear fuel cycle) | Nuclear weapon(s):<br>• Number<br>• Reliability<br>• Ability to stockpile<br>• Deliverability<br>• Production rate | • Disruption of operations<br>• Radiological release<br>• Nuclear explosives<br>• Radiation Dispersal Device<br>• Information theft |
| **Strategies** | • Concealed diversion<br>• Overt diversion<br>• Concealed facility misuse<br>• Overt facility misuse<br>• Independent clandestine facility use | • Various modes of attack<br>• Various tactics |

# Evaluations should consider…

- Adversary Context
  - Objectives
  - Capabilities
  - Strategies
- System design features relevant to PR&PP
- Safeguards and Security Contexts
- Policy considerations

➢ *Preliminary look at Gen IV designs in https://www.gen-4.org/gif/upload/docs/application/pdf/2013-09/gif_prppwg_ssc_report_final.pdf*

# What Evaluations Have Been Done?

- To evaluate PR&PP for a nuclear energy system, must consider its full fuel cycle- not just the reactor
- To date, this has not been done for any Gen IV system
  - *Some PR&PP studies* have been done outside of Gen IV*
- Gen IV system evaluations have been heavily focused on safety- especially for the reactor
- There has not been a full-scope PR&PP-type risk evaluation comparable to risk assessments for safety

**see addenda slides*

# Nexus of PR, PP, and Safety:
## *some features in common*

**ACCIDENT INITIATORS → SYSTEM RESPONSE → CONSEQUENCES**

**THREATS → SYSTEM RESPONSE → OUTCOMES**

- Safety and PR&PP should be considered from the earliest stages of design
  - Flow diagrams: preliminary safety hazard and PR&PP target identification and categorization
  - Physical arrangement: external events shielding, access control
- Safety and PR&PP can be complementary (in some ways) and in conflict (in others)
  - Design to maximize the complementarity

# Outlook – Some Questions to Consider

*…The world in 2050:*

- How many nuclear reactors will there be?
- Will accidents that affect the public be practically designed away?
- Will there be consensus on nuclear waste disposal?
- Will there be new institutional paradigms for nuclear energy?
- Will we eliminate nuclear weapons?

# ADDENDA

# Further Reading

- An extensive list of PR&PP-related publications can be found at

https://www.gen-4.org/gif/jcms/c_71068/prpp-bibliography

- Frequently asked Questions on PR&PP can be found at

https://www.gen-4.org/gif/jcms/c_44998/faq-on-proliferation-resistance-and-physical-protection

# *Implementation Activities Within National Programs*

- USA
  - Comparison of alternative fuel separation technologies (relative to PUREX)
    - COEX, UREX, pyroprocessing
    - Primarily improvements regarding non-state actors
    - Potential measurement challenges for large bulk facilities
  - Multi-laboratory assessment of reactor designs
    - SFR, HTGR, HWR, LWR
  - SMR Princeton study
    - Gen II vs SMR (LWR and fast-spectrum)

# *Implementation Activities Within National Programs (cont'd)*

- Japan
  - Evaluation of the methodology (JAEA and U. Bologna)
  - Comparison of SFR and LWR (presented at 2014 IAEA Safeguards Symposium)
  - Important to consider PR measures in a particular order
  - Difficulty incorporating impact of Additional Protocol
  - Facilitated a better understanding of PR, and how the methodology can help meet researchers' needs

# *Implementation Activities Within National Programs (cont'd)*

- Canada
  - Pre-licensing assessment of two advanced CANDU designs (ACR-1000 and EC6)
  - "Pared-down" PRPP approach, incorporating designer, SSAC and IAEA
  - Design improvements identified

# *Implementation Activities Within National Programs (cont'd)*

- Europe
  - "Collaborative Project for a European Sodium Fast Reactor" (CP-ESFR): study of impact of alternative core design options (another pared-down PRPP application)
  - MYRRHA (Belgium) – accelerator-driven research reactor: comparison with existing high flux test reactor and study of impact of alternative design variations